AD-A035 966 ROYAL NAVAL PERSONNEL RESEARCH COMMITTEE LONDON (ENGLAND) F/G 6/17
A STUDY USING INFRA RED THERMOGRAPHY OF CLOTHING ASSEMBLIES FOR--ETC(U)
MAY 76 R P CLARK, B J MULLAN, M R GOFF

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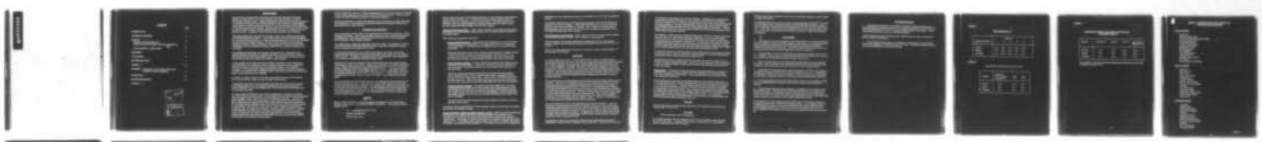

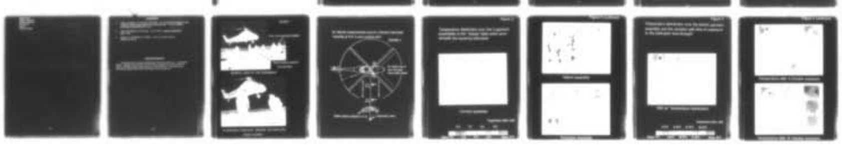

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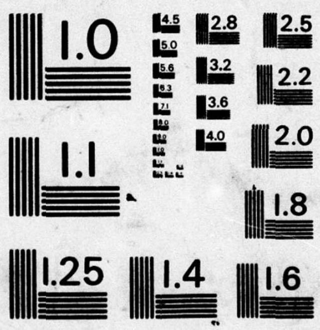

MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS-1963-A

CONTENTS

INTRODUCTION

The Environment Subcommittee of the Royal Naval Personnel Research Committee (RNPRC) has been asked to review and rationalise future requirements for extreme cold weather clothing in ships. Flight deck personnel concerned with helicopter operations are considered to be those most adversely affected by cold conditions in ships and their requirements for effective clothing are likely to be one of the base factors in deciding the overall extent of the protection needed. Extreme heat losses from the head and face, which are the most difficult areas to protect against the cold, give rise to complaints from the flight deck crews. Headaches in these cold and windy conditions occur frequently.

Preliminary studies have reported wind velocities and heat loss coefficients found underneath a hovering helicopter (Ref 1). The results of these measurements showed that the air velocities generated beneath a hovering Sea King helicopter could reach 33 m/s (64 knots) and that the flow was highly turbulent. The scale of this turbulence was such that the associated convective cooling coefficients were much greater than those expected from considerations of mean wind speed alone [h_c >80W/m^{2} ^{O}C at air speeds of around 13 m/s (25 knots)].

The hostility of the helicopter down-draught environment will be compounded in the seaborne situation where there are additional velocities across the deck due to surface wind and the motion of the ship through the water. The environment becomes even more hostile when the helicopters operate from ships in Arctic regions.

In these conditions the design of protective clothing is limited by several constraints. The insulation has to be adequate to protect the body and head from these extreme heat losses but at the same time the fabric must be flexible enough to allow sufficient movement so that marshalling, loading and fuelling operations can proceed unhindered. In addition, the clothing must be sufficiently tight to ensure that it does not fill with air and billow, as this makes the wearer unstable.

In an effort to produce clothing to meet these requirements three garment assemblies have been selected from items currently available to the Services.

A preliminary assessment of these assemblies has been made in the air flows beneath a hovering helicopter over land in winter in England and it is proposed that they be further evaluated in use at sea in HMS Hermes. The results of these preliminary tests are reported in this paper.

It is often considered sufficient, when garment assemblies are assessed, to measure skin surface and rectal temperatures. If the clothing is able to maintain these temperatures within acceptable limits, then the garments are regarded as adequate. However, the great variability of skin surface temperature, and its dependence on physical activity (Ref 2) means that spot measurements of skin temperature can easily be misinterpreted. It is also likely that the subtleties of heat loss at various parts of the body, which may not be representative of the body as a whole, but upon which a subjective assessment of comfort can rest, may easily be overlooked. It seems necessary therefore, in addition to skin temperature measurements, to measure the temperatures over the garment surfaces to determine any areas of abnormally high heat loss. Point measurements of garment temperatures using probes may be subject to the same errors in interpretation as when they are measured on the skin surface.

In view of this it was decided to combine conventional probe measurements with the technique of infra red thermography and to scan the whole of the garment surface. In this way areas of heat loss could be directly compared over different assemblies.

Since the head and face is a particularly difficult area to protect and is a region where high heat losses occur, it was decided to evaluate the temperature distribution and heat loss separately from the rest of the body.

MATERIALS AND METHODS

Three cold weather clothing outfits were assembled and assigned the designations, Current, Interim and Prototype. The Current assembly being that in use by flight deck personnel on HMS Hermes. The Interim assembly is that to be used in 1976 whilst awaiting the final development of the Prototype assembly.

The appendix lists in detail the components of the three outfits. Five subjects, A, B, C, D and E were clothed in these garments and positioned in the down-draught of a hovering Wessex 5 helicopter for periods of half an hour.

An AGA Model 680 Infra Red Colour Thermovision System was used to visualise the temperature distributions over the garment assemblies and the results were recorded on colour cine film. In addition to scanning by infra red thermography, skin temperatures were measured on the subjects using thermocouple probes.

Subjects B, C, D and E were monitored with a Light Laboratories Thermometer having the temperature sensor on the chest. Subject A was monitored with a Light Thermometer having 3 probes which produced an integrated temperature from the chest, arm and leg, separate additional probes were attached to his chest and back. This subject carried a back pack equipped with a Comark Differential Thermocouple Thermometer to measure the temperature difference between the hair and ambient air. Temperatures were also measured on the forehead, cheek and chin of this subject using an Ellab Thermocouple probe.

All of the subjects were exposed to the helicopter down-draught for three periods each of ½ hour in the course of 1 day. Each subject wore the Current, Interim and Prototype garment assemblies during one exposure. The subjects were grouped in an arc which was 10 ft out from the tips of the rotor blades and to the starboard side of the aircraft since this position was found to be where the maximum air velocities occurred. Wind speeds under the helicopter were measured using a cup anemometer and relative humidity was assessed using a sling hygrometer.

RESULTS

Figure 1 shows the general layout of the subjects and apparatus, and also illustrates the way in which the garments would fill with air and 'billow'. This tended to make the subject unstable.

Mean air temperature 5-6 ^{o}C D.B.

Relative humidity 75%

Surface wind - zero.

Figure 2 shows the ranges of wind speeds measured by a vane anemometer underneath the aircraft whilst hovering at 15 ft. Velocities in an arc around the engine intakes at a distance of some 40 ft dropped to around 8 m/s (15 knots). The clothed subjects were positioned in the area with the highest air velocities and the mean air speeds to which they were exposed fluctuated between 18-22 m/s (34-42 knots).

Analysis of thermographic film. Figure 3 shows examples of the steady state temperature distributions over the 3 garment assemblies after some 10 minutes exposure beneath the hovering helicopter.

These results are summarised as follows:

Current Garment assembly. The majority of the clothing surface was 2-3^{o}C above the temperature of the surroundings. No clothing areas had as low a temperature as the surroundings. The hottest areas of clothing observed were some 4^{o}C above the ambient.

The gloved hands did not show up any 'hot spots' which could lead to 'leakage' of heat. The back of the head was fairly well protected with the majority being 3^{o}C over ambient with small areas 4^{o}C above the surroundings. The worst areas for heat loss were under the chin, around the cheeks and near to the closure of the neck.

Interim Garment assembly. For this assembly the majority of the clothing was not more than 1^{o}C above ambient. Large areas were seen to be at the temperature of the surroundings. The greatest heat loss was found at tight fitting areas such as under the arms.

There were substantial hot spots over the gloves and around the wrist closures with temperatures some 3^{o}C above ambient (in one subject, temperatures on the gloves of 5^{o}C above ambient were noted). There were no noticeable hot spots over the back of the head. Some warm areas to the side of the neck were observed but the neck closure was generally good and notably better than in the Current assembly.

Prototype Garment assembly. The greater part of the clothing was at 1^{o}C above ambient although substantial areas of the assembly were at the temperature of the surroundings, however this area was lower in total than with the Interim assembly. Some areas over the back were 2^{o}C above the surroundings. In some subjects there was evidence of some heat loss from the area between the legs (more so than in the Interim assembly).

The gloves and wrist closures showed no hot spots and this was found to be the best assembly in this respect.

In summary, the best garment from the thermographic analysis was the Interim but with the gloves from the Prototype assembly.

Surface temperature changes with time of exposure to wind. Figure 4 shows the temperature distribution on the surface of the Interim garment assembly before exposure to the helicopter down-draught and twice during the exposure (after 2 minutes and 12 minutes respectively). In this figure the Thermovision setting was changed so that adjacent colours differed by 2^{o}C. In the steady state, before exposure, the various 'hot spots' showed up as red against a predominantly green background. With exposure to the wind, the temperature

distribution over the clothing became more even and there was a 2-3 $^{\circ}$C fall of temperature overall.

The variation of temperature over the head before exposure to the wind and with time of exposure, is also seen in Figure 4. The temperature fell by 4 $^{\circ}$C over most of the face (except the area of the eyes) within 2-3 minutes. After a further 10 minutes exposure this temperature fell by a further 2-4 $^{\circ}$C but the area around the eyes remained at least 12 $^{\circ}$C above the temperature of the clothing.

Probe temperature measurements. Table 1 shows the steady state temperatures obtained from the chest temperature probes of the 5 subjects for each assembly.

Table 2 shows the chest and back temperatures obtained from the fully instrumented subject A together with the integrated temperature obtained from probes on the leg, trunk and arm.

Table 3 shows the temperatures measured over the head of subject A during exposure to the helicopter down-draught.

DISCUSSION

In a limited study such as this, it is not possible to fully evaluate a complete garment assembly and this report sets out to make general comparisons between the tested assemblies and to indicate possible areas of high heat loss that might cause discomfort during actual use in Arctic conditions. In addition, the value of infra red thermography for use in the assessment of clothing is examined. When garment evaluations are based on skin surface temperature measurements the best garment would be that giving the highest temperatures. Conversely, when clothing surface temperature is used as a criterion, the aim is to have as small a difference between clothing and ambient temperature as possible in order to minimise heat loss.

In the present tests the chest temperature measurements were the coldest with the Current assembly. There was no consistently greater or lower temperature difference over the chest between the Interim and Prototype assemblies for any one subject, (the range of temperature difference being between 0.1 $^{\circ}$C and 2.4 $^{\circ}$C). It would therefore be difficult to recommend that either of these assemblies would be the more effective from consideration of these skin temperatures alone. The same remarks apply to the results from subject A for the single measurements made on the chest and back. There would be slightly more certainty in recommending the Prototype assembly from the results of the integrated temperatures over this subject which are shown in Table 2. However, in this table there are certain apparent inconsistencies that require explanation.

The chest temperatures show no practical differences between assemblies. The back temperatures would indicate that the Interim assembly would be the most suitable with a substantially higher temperature than in the other two assemblies. This is not reflected in the integrated temperatures measured on the arm, leg and trunk where the Prototype assembly would be judged most suitable. An explanation for this is sought in the extreme variability of the skin surface temperature which has been revealed by infra red thermography and which is illustrated in Ref 2.

If temperature sensors are removed and replaced between experiments the exact re-positioning is a critical factor in obtaining a valid comparison. A position error of 1-2cm

can represent a temperature error of several degrees. It therefore seems unlikely that temperatures measured with single (or even 3) probes can be relied on to adequately evaluate the effectiveness of a garment assembly without taking a great many measurements from many exposures. It seems likely that factors such as local areas of heat loss from the assemblies will greatly determine the long term effectiveness of a garment. Thermography reveals such areas of heat loss and is a useful tool in the overall assessment of the effectiveness of a garment assembly.

From Figure 4, which shows the variation of temperature with time of exposure, it is seen that after exposure to the wind the temperature distribution over the garment surface becomes much more uniform. The temperature picture before this exposure shows areas of high temperature and therefore large heat loss. It follows that these areas will lose the most heat in the wind in order to reach the lower and more uniform temperature. Should the subject then seek shelter from the wind the original temperature patterns will re-appear and on a second exposure these areas will again lose large quantities of heat.

The high heat loss rates in these air streams may mask these local areas of heat loss which were observed in the 'still air' conditions, (a similar situation is seen in the uniform skin temperatures found in subjects immersed in water (Ref 3)).

Thermographic pictures of subjects exposed to the wind show up areas of high heat loss and give an overall clothing temperature, the 'still air' thermographs need to be examined in order to predict the regions of high heat flow from the skin through the garment layers to the outer surface.

Head heat loss. The question of heat loss from the head and exposed parts of the face is important since there are many complaints about the inadequacy of the head protection from crews working beneath helicopters. Thermography shows the exact extent of these warm unprotected facial areas.

From measurements made on the thermographic pictures of the subjects in this study, it is seen that the hot areas of the face represent about 2% of the front projected area (ie face = 1-1.5% of total body area). Using the results of the previous work (Ref 1) where mean overall convective coefficients as high as 80 W/m^2 $^\circ$C have been measured it is possible to calculate heat losses from the face. As an example of the quantity of heat lost from the face during these experiments we may consider a subject with a surface area (clothed body) of 2 m^2 where the exposed facial area is 1.5% of this ie 0.03m^2. For a garment assembly where the mean clothing temperature is 2 $^\circ$C above the surroundings (which were at 5 $^\circ$C) the total heat lost by convection = 80 x 2 x 2

= 320 watts

The face temperatures measured were of the order of 18 $^\circ$C and the heat lost from here would be some 0.03 x 80 x 13

= 31.2 watts

ie the exposed face loses 10% of the total.

In a garment assembly where the clothing is only 1 $^\circ$C above ambient the total convective loss is about 160 watts. The heat loss from the face would still be 31.2 watts which this time represents some 20% of the total.

With such high cooling coefficients the heat loss is particularly sensitive to small changes in surface temperature.

It is noted that the quoted values of convective cooling coefficient of 80 $W/m^2 {}^oC$ represent an overall mean value. As indicated in Ref 1 the circumferential distribution can give rise to even higher coefficients at areas facing directly into an air flow (by about a factor of 2). In the case of the last example the body heat loss would be 160 watts and the head loss could be some 63 watts which is some 39% of the total for a subject facing directly into the wind.

CONCLUSIONS

1. With exposure to the down-draught of a hovering helicopter the surface temperatures of various garment assemblies has been compared, using infra red thermography and the Interim assembly has been shown to have lowest surface temperature indicating its suitability at heat retention by the body. The surface temperatures observed are seen to be much more uniform in the down-draught than in 'still air' conditions.

2. Thermography reveals the local hot spots over garment assemblies worn in 'still air' conditions. These are the areas where the heat loss will be greatest both in the 'still air' and also when the subjects are exposed to high velocity winds.

3. The very warm areas over the face have been demonstrated in all of the garment assemblies. With the high heat loss coefficients previously measured beneath hovering helicopters, these areas could account for up to 40% of the total body heat loss.

4. Underneath a hovering helicopter an excess temperature of 1 ^oC over any garment assembly can increase heat loss from a subject by upwards of 80 W/m^2. This indicates the sensitivity of heat loss to excess temperature in these environments and emphasises the importance of adequate and uniform insulating properties of the garment assembly.

5. All of the assemblies tested in this study tended to fill with air and billow and flap. This was unsatisfactory as the subjects easily became unstable and had difficulty in standing.

6. The information obtained with thermography was additional to that obtained using thermocouple probes. The data from the probe measurements proved ambiguous and limited and no clear recommendations could be made from these measurements alone. This may not be true in a longer trial where many temperatures could be measured during multiple exposures and where the results could be statistically treated.

Thermography on the other hand has proved a useful tool in immediately assessing the temperature pattern over a COMPLETE garment assembly. It has enabled hot spots to be identified and in addition has accurately defined the extent of the unprotected face. A thermographic study places no physical constraint on the subjects since it is a 'no-touch' technique and the subjects can perform any task unhindered by thermocouple leads etc.

RECOMMENDATIONS

1. Thermography should be used (possibly in conjunction with thermocouple probe measurements) in an extended comparison of temperature distribution and heat loss from the various assemblies in 'still air' as well as in the helicopter down-draught. These trials should be carried out at sea in operating conditions.

Attention should be focused on tightness of fit, effectiveness of closures, insulation of gloves, amount of billowing etc.

2. It seems likely that the only way of adequately reducing heat loss from the head would be by providing all enveloping helmets with visors. Considerable design effort and evaluation is indicated to overcome this problem.

TABLE 1

Chest temperatures °C

Garment assembly	Subjects A	B	C	D	E
Current	31.6	30.1	31.8	29.4	28.6
Interim	31.8	32.6	34.3	33.6	35.0
Prototype	31.9	35.0	34.0	33.9	34.6

TABLE 2

Temperatures over fully instrumented subject A

Garment	Integrated temp. arm, leg and trunk °C	Chest °C	Back °C
Current	29.5	31.6	32.0
Interim	30.4	31.8	33.6
Prototype	33.0	31.9	32.0

TABLE 3

Temperatures measured over the face and head of fully instrumented subject A

Garment	Forehead °C	Cheek °C	Chin °C	Hair/ambient difference °C
Current	21.5	14.0	12.5	18.0
Interim	21.0	16.0	13.0	23.0
Prototype	21.0	18.8	18.0	24.0

After exposure, when the aircraft had departed these temperatures rose within 5 minutes by between 5-8°C.

Appendix - Components of the Current, Interim and Prototype Garment Assemblies

Current Assembly

String Vest
Drawers Knitted Long
Shirt and Trousers (Cotton) Overalls
Jersey Seamans White
Jacket Foul Weather
Trousers Foul Weather
Flight Deck Helmet
Helmet Balaclava
Ear Defenders
Gloves Inner fleece
Gauntlets PVC
Stockings White Seaboot
Felt Insoles
Boots leather half wellington

Interim Assembly

Vest ECW
Drawers ECW
Shirt Cotton
Jersey Wool Heavy
Combat Smock
Combat Trousers
Smock G/W Reversible
Trousers G/W Reversible
Headover
Cap Cold Weather
Wristlets Woollen
Gloves inner fleece fabric
Gloves winter fireball
Socks Arctic

Prototype Assembly

Vest ECW
Drawers ECW
Quilted liner jacket
Quilted liner trousers
Overalls
Jersey Wool Heavy
Windproof trousers
Smock G/W Reversible
Trousers G/W Reversible
Headover
Cap Cold Weather
Wristlets Woollen

/Mittens

Mittens inner
Mittens windproof
Mittens waterproof
Sock Arctic
Insoles
Boots Ski March

REFERENCES

1. Clark, R P Mullan, B J and Goff, M R (1975). Air velocity and convective cooling coefficient measurements beneath a Sea King Helicopter. Report to RNPRC Environment Subcommittee (ES 1/76).

2. Clark, R P Mullan, B J and Pugh, L G C E (1974). Journal of Physiology, 239, 81-82p.

3. Burton, A C and Edholm, O G (1955). Man in a cold environment. Edward Arnold Ltd.

ACKNOWLEDGEMENTS

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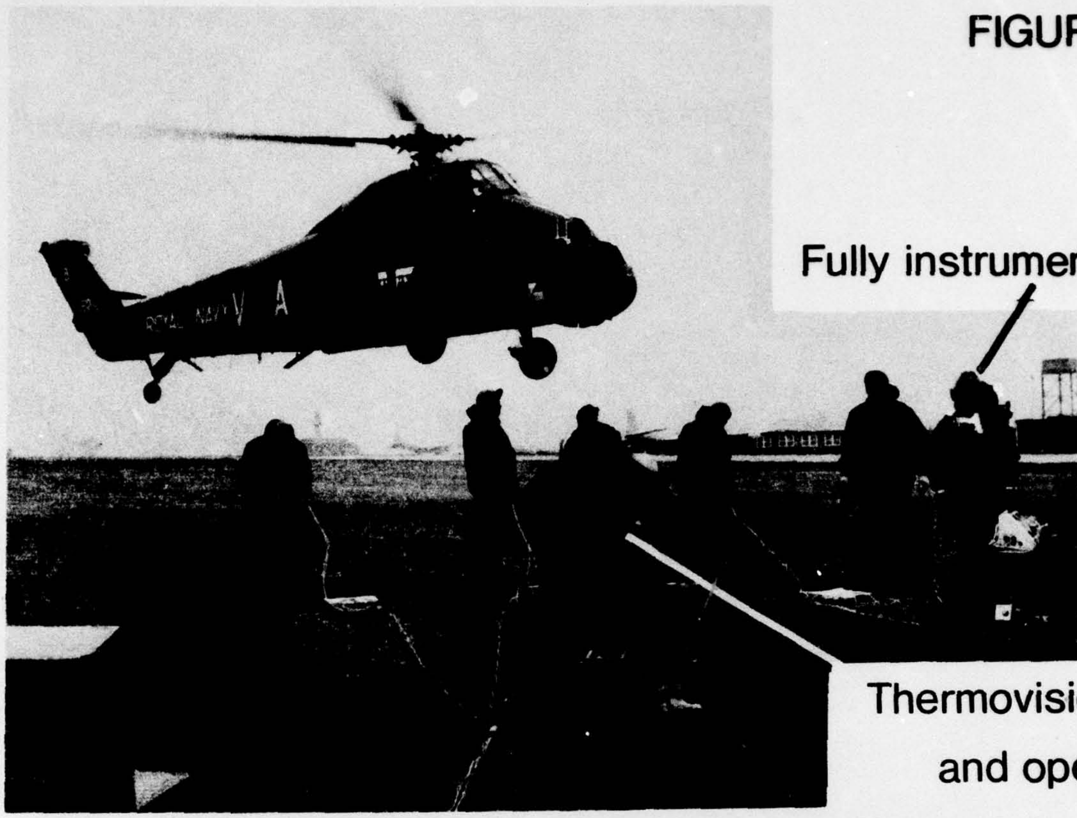
FIGURE 1



Fully instrumented subject

Thermovision camera and operator

GENERAL VIEW OF THE EXPERIMENT

An illustration of garments "billowing" and making the subject unstable

Air velocity measurements around a Wessex helicopter hovering at 15 ft. in zero surface wind

FIGURE 2

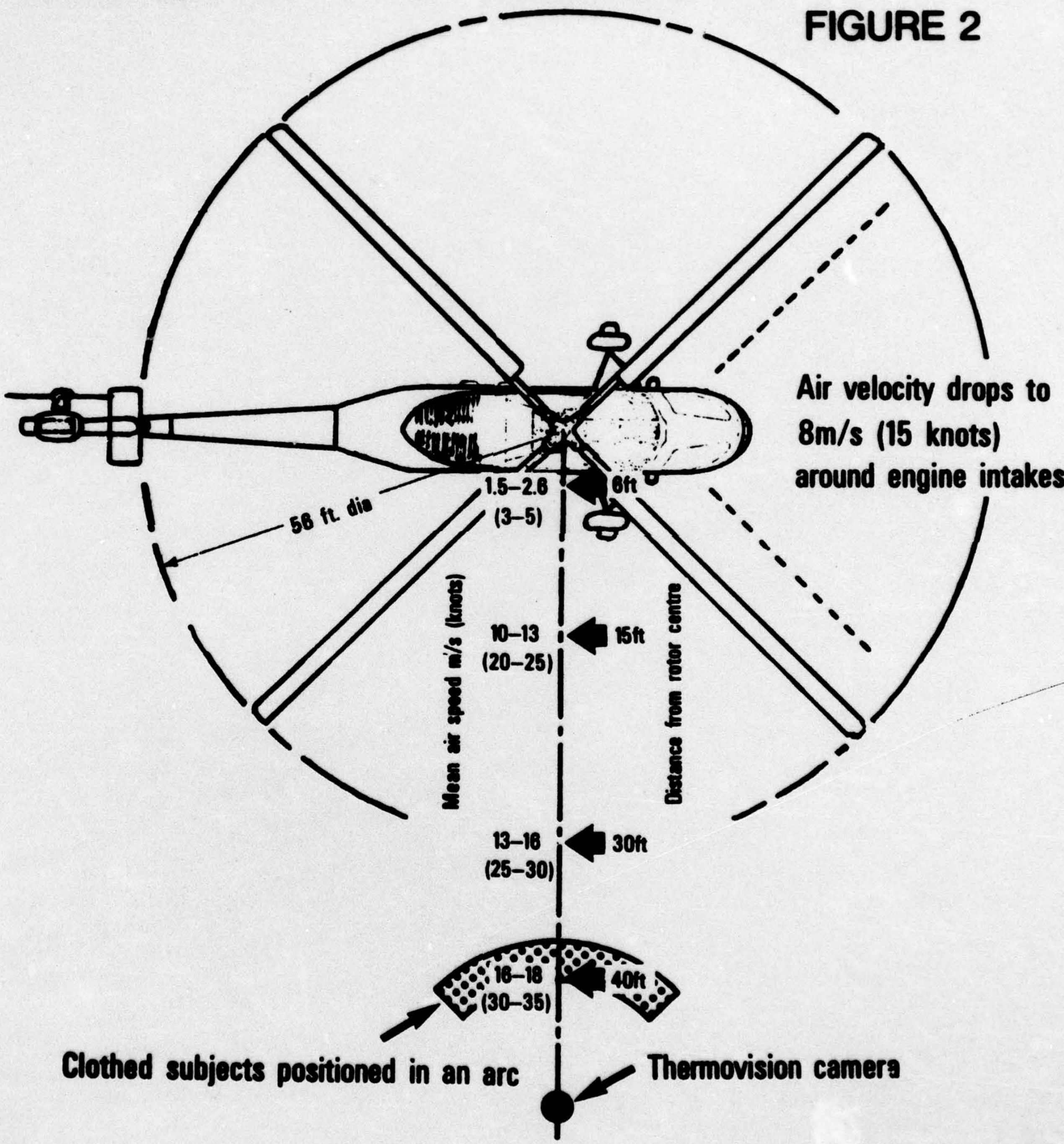
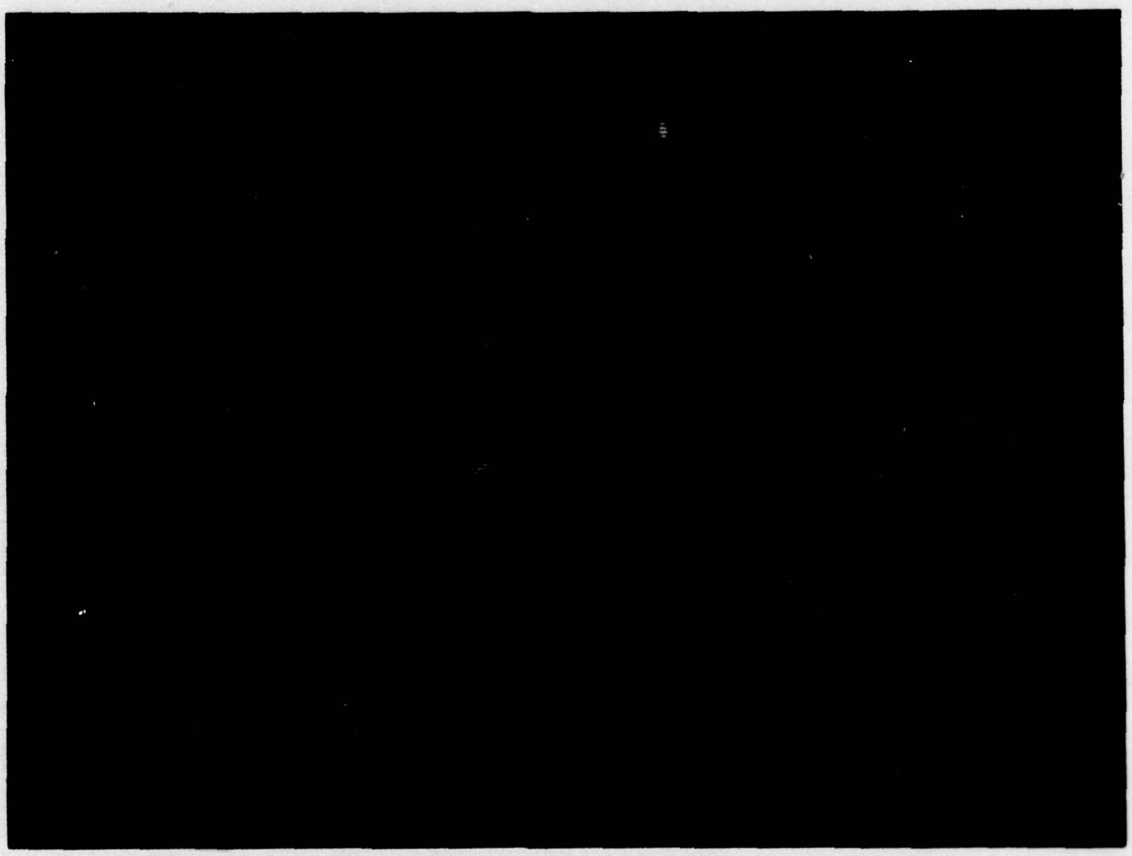


Figure 3

Temperature distribution over the 3 garment assemblies in the "steady" state when worn beneath the hovering helicopter



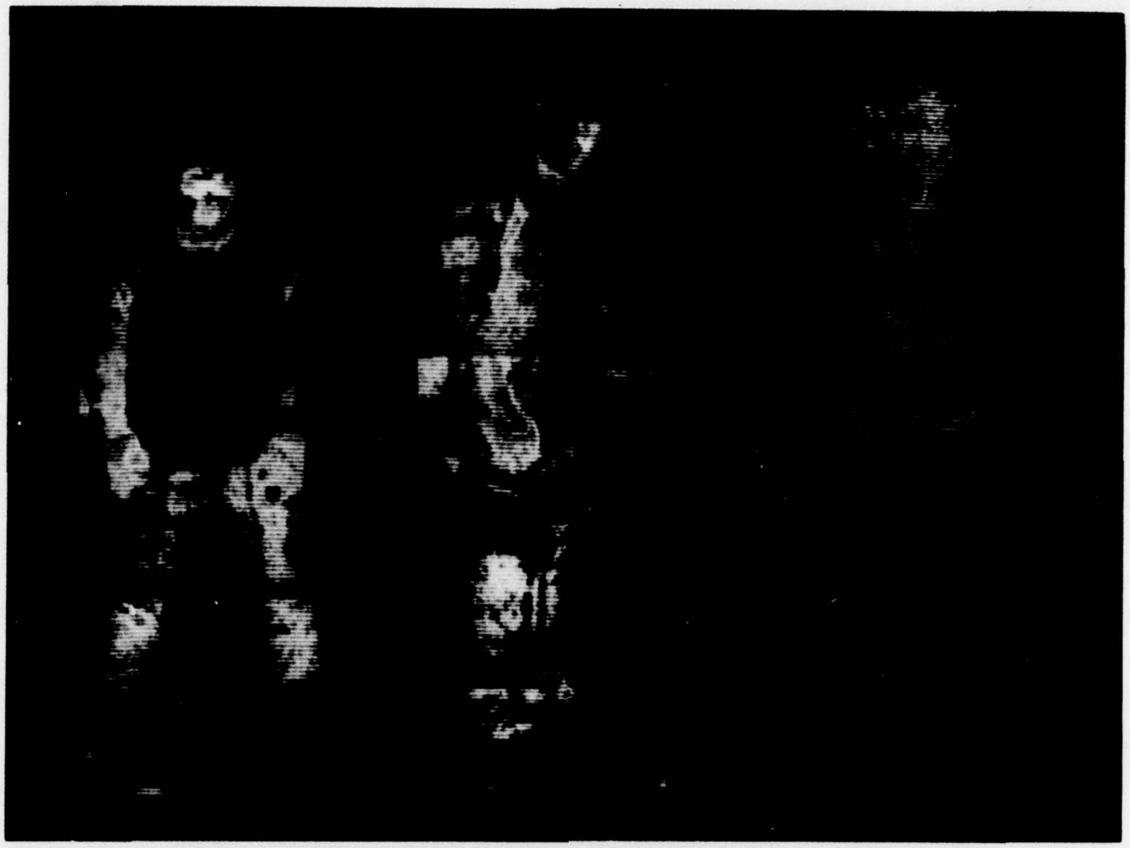
Current assembly

Temperature-colour code

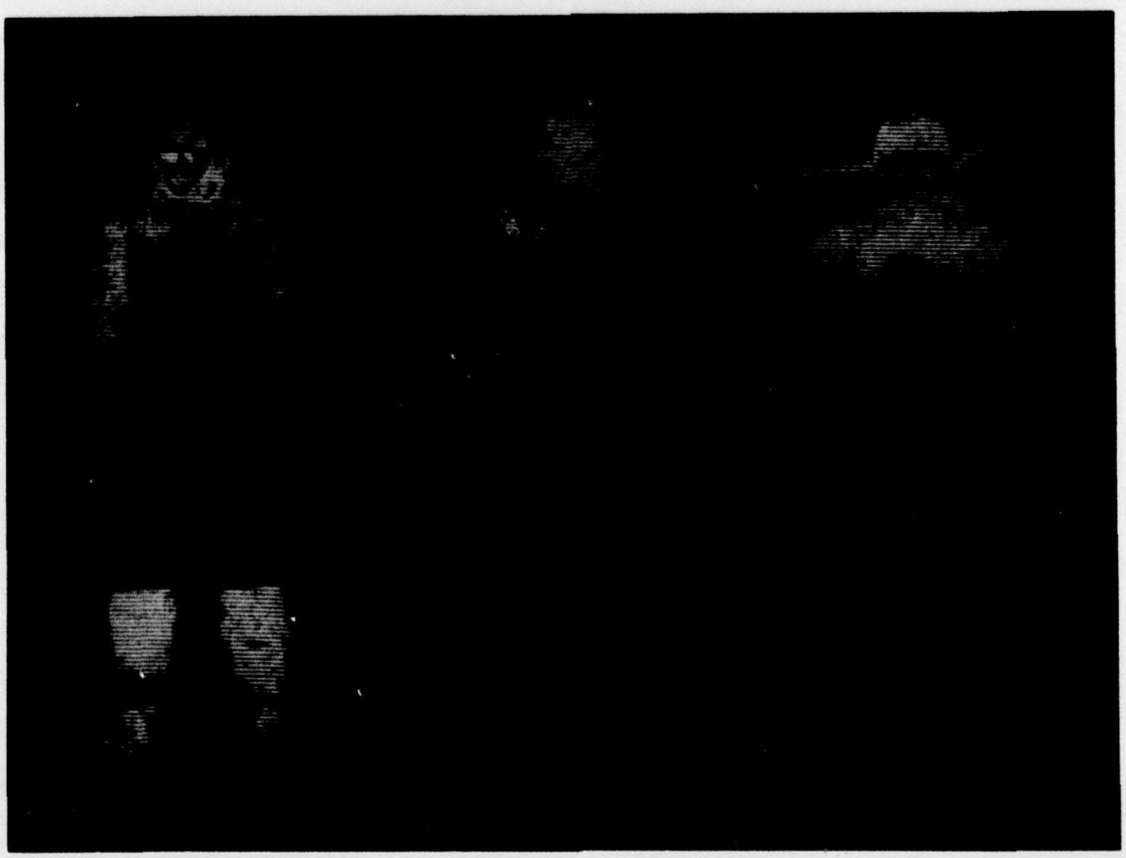
5°C 7°C 9°C 11°C

Below 4°C 6°C 8°C 10°C Above 12°C

Figure 3 continued



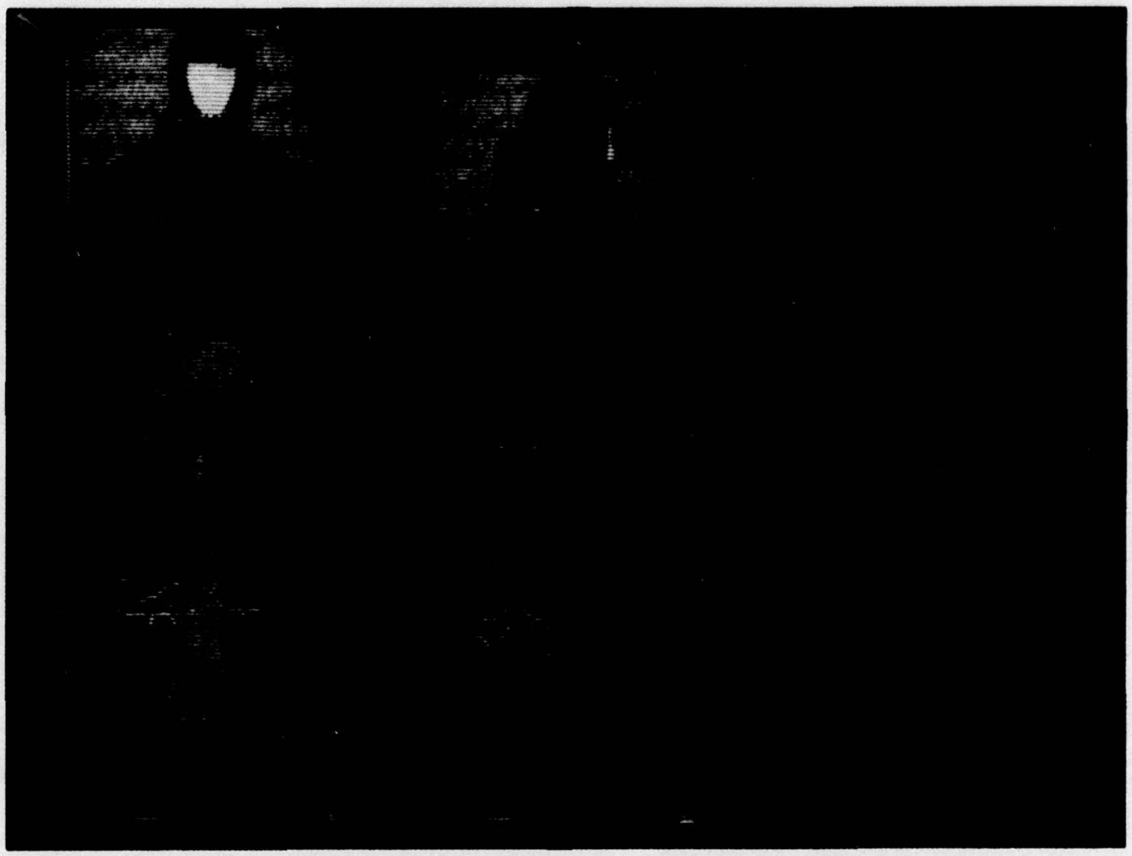
Interim assembly



Prototype assembly

Figure 4

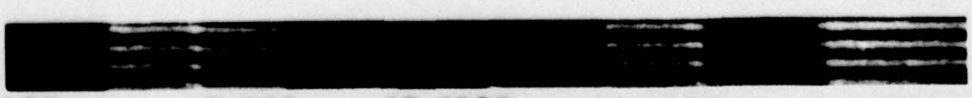
Temperature distribution over the Interim garment assembly and the variation with time of exposure to the helicopter downdraught



"Still air" temperature distribution

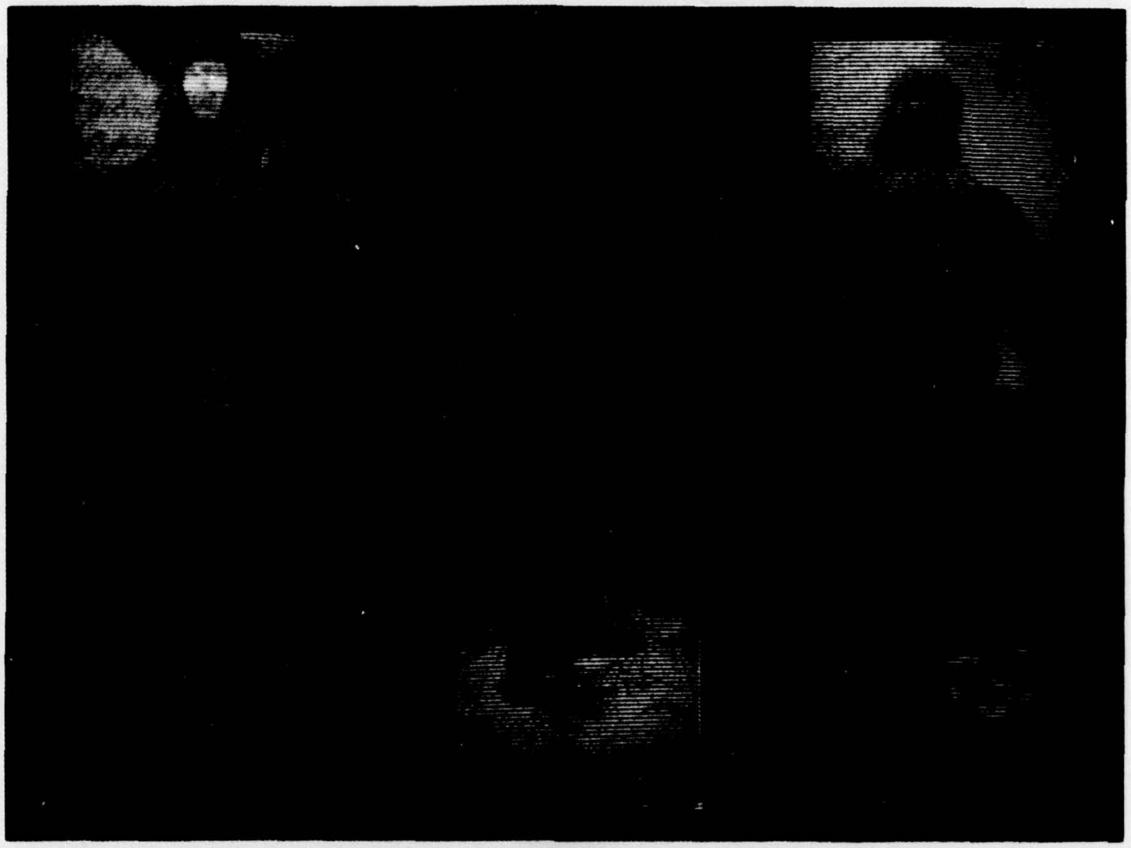
Temperature-colour code

4-6°C 8-10°C 12-14°C 16-18°C

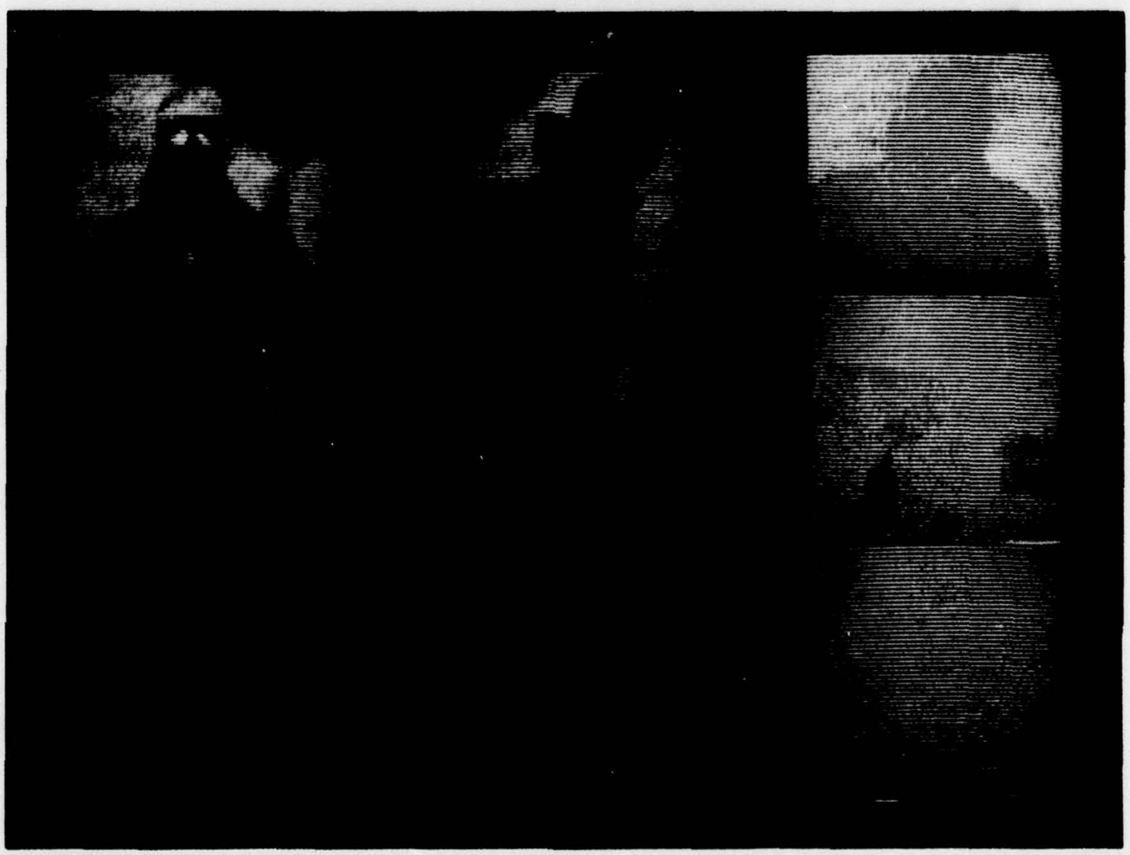


Below 4°C 6-8°C 10-12°C 14-16°C Above 18°C

Figure 4 continued



Temperature after 2 minutes exposure



Temperature after 12 minutes exposure